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Assessing the performances of hydraulic concrete composed with used glass powder for sustainability of constructions in Congo

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Abstract
This paper presents a study on the assessing of the physical-mechanical properties of hydraulic concrete composed with the used glass powder in the local context of Congo. This study is part of a vision of sustainable development in civil engineering through the valorization of glass waste (i.e., the use of glass powder), against a decrease in the amount of CO2 (i.e., the carbon gas) released by the cement industry each year. The rates 2,5%, 5%, 7,5% of glass powder were used as a partial replacement of cement, and as an admixture to testing the concrete performances. The proportion of concrete with 5% glass powder added gives a good compressive strength on cylindrical specimens, this rate correspond at a fixing point of concrete composition. The density of this sample (2,375g/cm3) corresponds to the range of light concrete. The density and compressive strength of concrete develop in a highly correlated manner when glass powder is used as a partial cement replacement. This is due to the joint contribution of glass powder and Portland cement on the microstructure of the concrete, which consists in the improvement of its physical-mechanical properties through pozzolanic activity. Also, the rates 2,5% and 5% used as an admixture shows that the glass powder has accelerator effect on the concrete curing. With 7,5% rate, the used glass powder has retarder effect on the concrete curing. These results confirm the role of glass powder with adequate proportions in improving of the geotechnical performances of hydraulic concrete.

1. Introduction

The civil engineering infrastructures (road, buildings…) represents the technical elements to contribute a sustainable development in a country [1,2]. As according [3], the construction field (i.e., the manufacturing, transportation and use of construction materials) is responsible of 38% on the total global gas emissions. In this, the construction of infrastructures requires the use of materials with low costs and environmentally friendly. The concrete is the common material used in construction for its acceptable performances over time. This is ordinary mixture of aggregate (gravels, sand), a binder (respectively the Portland cement) and the water, which react together to giving it the excepted performance[4]. However, divers research [5,6,7,8] indicates that the manufacture of cement induce a negative impact on the environment, which is approximately 7% of the overall carbon (CO_2) footprint. To reduce this impact of cement manufacturing, different research's was recently on the addition of the glass powder as partial replacement of cement for the composition of concrete [9,10, 11,12]. The use of non-conventional material (respectively the recycled glass) in the concrete composition contribute to reduce the quantity of solid waste in cities and the construction costs related at costs of manufacture and transportation of cement or gravels. More, the reuse of recycled glass (powder) as a partial cement or aggregate replacement in concrete is justified by its ability to improve during time the use properties of concrete: stabilization of the mechanical strength of the concrete over time, the correction of its global porosity by the filling effect of the glass powder, the permeability of concrete by hydration effect of the glass particles[9,10,12,13].

Despite these large researches, the opinions of researchers remain disparate on the optimal glass powder content to add in each use context of concrete. Belebchouche et al. [9] have shown that the addition of 15% glass powder provides acceptable mechanical strength's, improve the global porosity, but increases the hydration of the concrete. Khan et al. [10], and Mirzahosseini et al. [13] has shown that the added of 25% glass powder is the optimal content to replace the cement in concrete. Du and Tan[11] has indicate that 30% glass powder in partial cement replacement provides a good compression strength of concrete, but the resistance to water and chloride penetration require 60% as dosage of glass powder. Drzymata et al. [12] have conclude that the use of 30% recycled glass as a partial gravel replacement provides the efficient improvement of concrete properties. As reported in the literature, the durability of the construction also depends strongly on the choice of materials, notably the dosages of elements in the case of concrete[14,15].

In this context, and for different reasons: on the on hand, the variability of the recycled glass (i.e., their nature) and tested glass powder contents. And other on hand, the geotechnical changes of the granular of an environment at another [16], it is necessary for each construction context, to testing different levels of cement replacement with the glass powder on the physical-mechanical properties of concrete. This also was recommended by Du and Tan [11], which estimates the significant to study the differs levels of cement replacement on the mechanical performances and concrete durability. Indeed, even if the addition of glass powder has been tested at high dosages 10 to 60% in these works, to our knowledge very few studies have been carried out on contents below 10%, which would be an interesting recommendation to take into account the realities of each country (i.e., manufacture and treatment of waste glass…). The pozzolanicity of artificial material, i.e., manufactured by industrial process, is define as its ability or of a natural material to react with Ca(OH)2 element in the presence of water [17,18]. The pozzolan reaction rate in concrete mixture depends on its intrinsic characteristics of pozzolan, such, chemical composition and content of active phase. According to ASTM C618 standard [19], the recommended quantity of pozzolan in a composite material as the concrete must verifying the relationship SiO_2+ Al_2O_3+Fe_2O_3 > Coal Fly Ash. It is F class if the Coal Fly Ash is 70%, and as C class if ≥ 50%. So for each glass powder mixture with cement always verify the pozzolanic activity. In this order, the main aim of these present study is to evaluate the effect of the addition of 2,5% to 7,5% recycled glass powder as cement replacement and adjuvant on the physical-mechanical properties of hydraulic concrete. The essential idea is to fill in the gaps on this subject, in particular in the local context of Congo for which the studies do not actual existing to our knowledge. The optimal glass powder content is proposed on basis of realized laboratory tests.

2. Material and method

2.1 Waste glass powder

The used glass samples were taken from the public waste dumps in Brazzaville city (Congo, see Fig.1) and washed with the water before being crushed. These used glasses are of the soda-lime glass family which is commonly sold in the Congo. To obtaining the glass powder of recommended particle seize (i.e., less than 45μm), these glass scraps were ground in a ball milling machine (respectively the used machine for Los Angeles test [20]). To characterize the pozzolanic activity of this glass powder in concrete, we consider its typical composition (soda-lime glass) as according by different research [18,21] and presented in Table 1. The summation of the quantities of SiO2, Al2O3 and Fe2O3 elements is 74, 74% > 70% confirms the inactivity of selected glass powder for mixture of hydraulic concrete.

Table 1. Chemical composition of the associate glass powder

Elements	SiO2	Al2O3	Fe2O3	CaO	Na2O	MgO	PAF
%	73.0	1.0	0.74	7.0	15.0	4.0	129

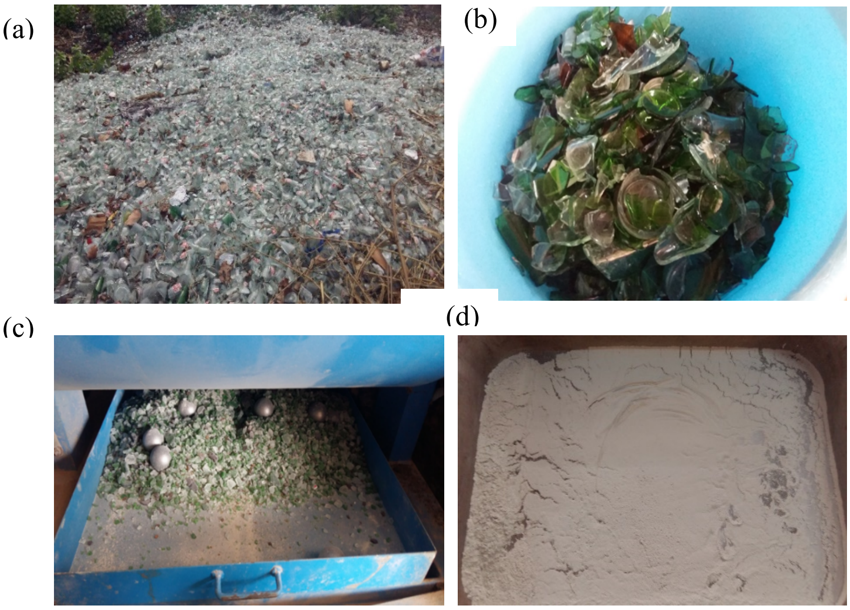

Figure 1. Used glass powder, (a) Kisoundi waste dump, (b) process of glass preparation, (c) used glass shredding process, (d) obtained glass powder after screening.

2.2 Cement and conventional granular

The used lime is a Portland cement at limestone of type 42,5N (were 42,5N represents the normal strength) manufactured by Dangote Company in Congo (Fig.2). The coarse aggregates used of class 5/15 and 15/25 come from the Nkombe quarry. The fine sand 0/1 was extracted from the banks of the Congo River.

Figure 2. Sample of the used cement type

2.3 Mixing water

The water used for mixing the granular mixtures come from a local drinking water well in project area. The chemical testing reported that its pH > 6.

2.4 Characterisation and testing concretes

The glass powder was incorporated at rates 2,5%, 5%, 7,5% as a partial replacement of Portland cement (42,5N) by weight, and as reinforcement of cement (i.e., admixture). For each tested sample, the mixes were design with the absolute volume method as according to ACI standard [22]. The geotechnical characterisation testing has realized on all used materials. The granulometric analysis (respectively by sedimentation and sieving) which determine the distribution of the particles seize of material is realised in conformity of NF EN 933-1[23]. The cleanliness of the materials (sand, gravels, glass powder) was determined by the sand equivalent test (NF EN 933-8 standard) [24], and soil methylene blue tests (NF EN 933-9 standard) [25]. The specific weight determining the weight per unit volume of the solid grains of the soil was carried out in accordance with standard NF EN 1097-7 [26]. The apparent density determining the ratio between the mass of dry aggregate and the volume it occupies without compaction including the volume of intergranular voids is measured in according to standard NF EN 1097-3[27]. It characterises the microstructure of aggregates. To determine the mechanical resistance of 5/15mm and 15/25mm aggregate, the Los Angeles fragmentation test by impact [20], and Micro-Deval fragmentation test by impact (NF EN 1097-1[28]) was carried. For each curing time and concrete mixture, nine cylindrical specimens of dimensions 16x32 cm were made to testing the compressive strength according to NF EN 206-1 standard [29]. Compressive strength (MPa) formula = Load (N)/Area (mm^2) [8]. Table 2 provides the calculate quantities of materials mixtures for the concrete composition. This cocnrete composition was determined by Dreux-Gorisse method where the refer strenght is C20/25 for a water/cement ratio W/C = 0.52, and the refer average workability A_{ff} = 7± 2cm to according a NF EN 206-1 standard [29].

Table 2. Summarize of concrete composition for 1m^3: CG-concrete without glass powder, CGP#-concrete with glass powder added as a partial replacement of cement, CG#-ordinary concrete with glass powder added as an admixture.

Material	Concrete dosage						
	CG#	CGP#2,5%	CGP#5%	CGP#7,5%	CG#2,5%	CG#5%	CG#7,5%
Cement 350kg/m^3	50kg	48,75kg	47,5kg	46,3kg	50kg	50kg	50kg
Sand 0/1	60L	60l	60l	60l	60l	60l	60l
Fine gravel 5/15	60L	60l	60l	60l	60l	60l	60l
Coarse gravel 15/25	60L	60l	60l	60l	60l	60l	60l
Water	29.4L	29.4L	29.4L	29.4L	29.4L	29.4L	29.4L
Glass powder	0	1.25kg	2.5kg	3.75 kg	1.25kg	2.5kg	3.75 kg

The geotechnical properties of the proposed concretes were modelled using OriginPro 2019b software[1], that offer an intuitive analysis of data, as illustrated in next section.

3. Results and Discussion

3.1 characteristic of raw materials and mixtures

The particle size curve of the used glass powder (Fig.3) shows that it has a tight and well distributed grain size distribution, according to the values of Cu =1,4 « uniformity coefficient » and Cc = 1,13 «compliance coefficient » between 1 and 3 [23]. The percentage of this glass powder on the 0,063mm sieve is 28,6 % inferior at 35%, meaning that it contains fewer fine particles.

[1] https://rahim-soft.com/originpro-2019b-free-download/

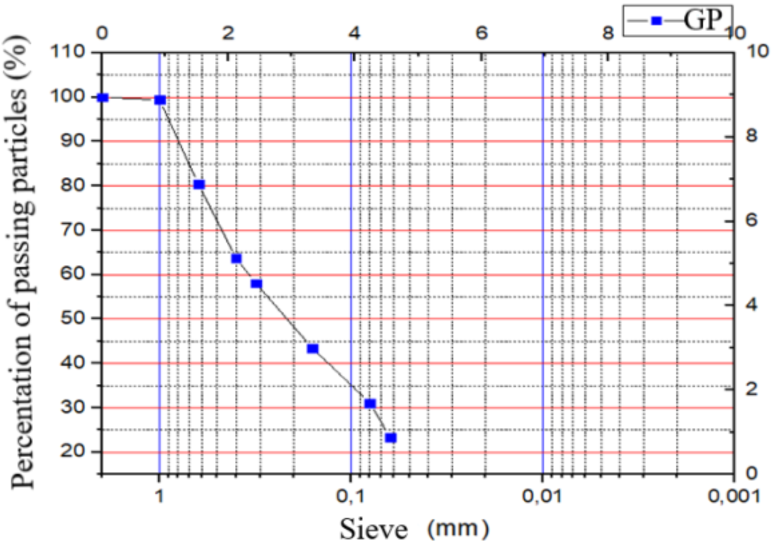

Figure 3. Graphic, granulometry of used glass powder,GP.

The Table 3 presents the results on the geotechnical characterisation of materials properties. The value of sand equivalent SE= 88%> 70% and that of VB =1,20 %< 1,50% means that the aggregates are clear and suitable to making the concrete [24,25]. The apparent density value (appMV) for each aggregate type is superior about standards exigence (1,2t/m^3). The MDE and LA tests were performed on the reference aggregate fraction (10/14). The average value of MDE = 17% <35% and LA = 28 %< 40% indicates that the aggregates has a good mechanical strength according the standards; the relationship between LA+MDE ≤ 50% is verified. All these testing shows that the selected materials and glass powder are perform for the composition of an acceptable hydraulic concrete.

Table 3. Summarize of geotechnical characterization of the material properties:
MDE- Micro-Deval fragmentation index, LA- Los Angeles fragmentation index.

Material	**Geotechnical properties**					
	Specific weight (t/m3)	Apparent density (t/m3)	Methylene bleu value (VB, g/%)	Sand equivalent (SE, %)	MDE (%)	LA (%)
Sand 0/1	2.62	1.50	-	88	-	-
Fine aggregate 5/15	2.63	1.38	1.15	-	17.04	28.00
Coarse aggregate 15/25	2.65	1.36	1.15	-	17.04	28.00
Glass powder GP	2.43	1.23	1.20	-	-	-

3.2 Results of testing on concrete

3.2.1 Workability and density of fresh concrete

The workability index (i.e., the measure Slump with Abraham's cone) for the concrete with glass powder as added is 7cm and 8cm. That of ordinary concrete without of glass powder added is 6 cm. All the mixed proportion of glass powder achieved acceptable workability, showing the effect of the glass powder added on the improvement of the concrete consistency.

3.2.2 Compressive strength and density of concrete

The density of differs concrete samples is summarizing in Table 4. We find quite similar densities (values varying from 2,351 g/cm^3 to 2,380g/cm^3) in the two configurations of using glass powder in the concrete composition (i.e., as an added and admixture) and the ordinary concrete without adding glass powder. This shows that the glass powder used as an admixture has no volume mass effect on the hardened concrete.

Table 4. Concrete density for all samples

Concrete	Samples						
	CG#(	CGP#2,5%	CGP#5%	CGP#7,5%	CG#2,5%	CG#5%	CG#7,5%
Density (g/cm3)	2.349	2.366	2.375	2.380	2.370	2.380	2.351

The Figure 4 shows the evolution of the compressive strength after 7, 14 and 28 days for the ordinary concrete using the glass powder as an admixture. At 7 days the compressive strength varying at 25MPa to 27MPa, but at 14 and 28 days this strength varying of 30MPa to 33MPa. It is observed glass powder acts as a hardening accelerator with 2,5% to 5%; 7,5% being the optimum (i.e., the stabilization point of the glass powder pozzolanic action). On the other hand, it is a hardening retarder with 7,5%, in as the compressive strength drops.

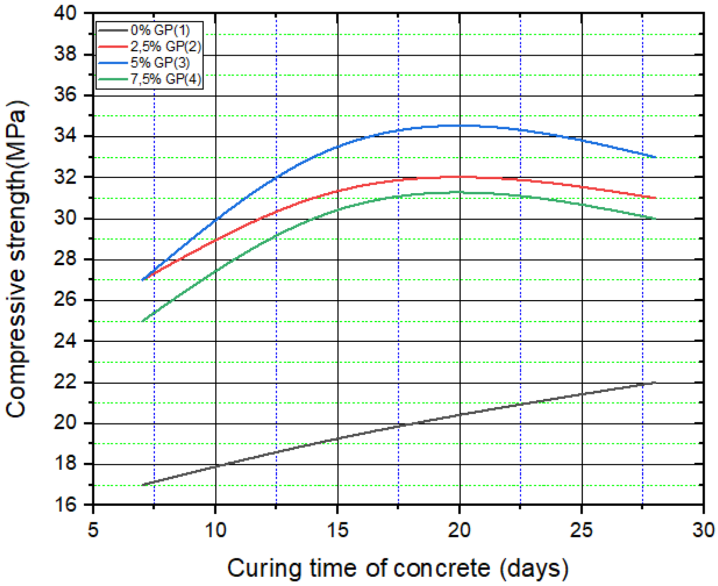

Figure 4. Compressive strength of ordinary concrete with glass powder as admixture.

To observe Figure 5, it can be seen that the compressive strength of the concrete changes over time with the increase of glass powder content (2,5%, 5%, 7,5%), this can justify the pozzolanic activity of the mixture glass powder and Portland cement. The compressive strength at 7days is 24MPa to 27MPa, 14days (26MPa to 29MPa) and 28days (27MPa to 33MPa). For ordinary concrete samples without glass powder added, the compressive strength is, 17MPa (7days), 19MPa (14days) and 22MPa (28days). Indeed, the pozzolanic activity is the chemical reaction caused by the mixture of Portland cement and glass powder to increase the physical and mechanical properties of concrete when pozzolans expand [30]. This result is in according with several research studies which have shown the effectiveness of adding glass powder as a partial replacement for cement up to 20% content [9,10,31]. Compared to the reference strength class of concrete (i.e., C20/25), it can be noted that the addition of 5% gives optimum strengths whatever the curing time, thus minimizing the effect of heat of hydration of the concrete.

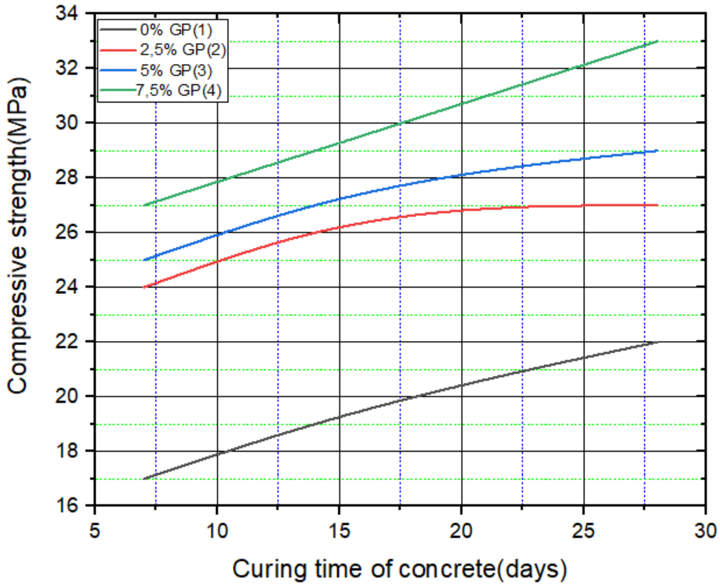

Figure 5. Compressive strength of concrete with glass powder as a partial replacement of cement.

Figure 6 presents the evolution of compressive strength for different ratio of glass powder used as a partial replacement of cement and as an admixture of concrete to summarize the values of Figure 4 and 5.

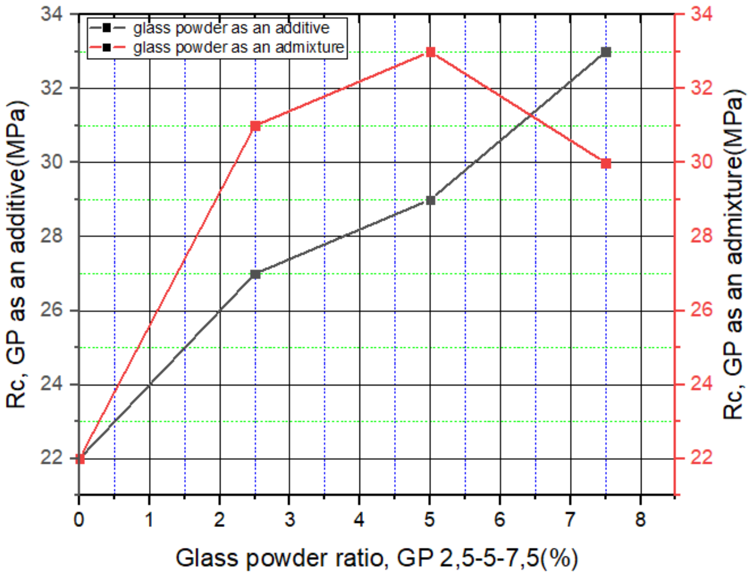

Figure 6. Evolution for compressive strength in function of glass powder ratio0%, 2,5%, 5%, 7,5% used as an admixture and additive: Rc-compressive strength, GP-glass powder .

Figure 7 shows the evolution of the compressive strength of different concrete samples as a function of the glass powder content and the density of the hardened concrete. These three quantities are highly correlated by a linear relationship, explaining the fact that an increase of glass powder is responsible for the cementing of the pores in the concrete microstructure. The proportional evolution of the compressive strength with the density of the hardened concrete in relation of the glass powder content used as an additive seems to reveal a good porosity of the proposed concrete, thus justifying its durability in aggressive environments.

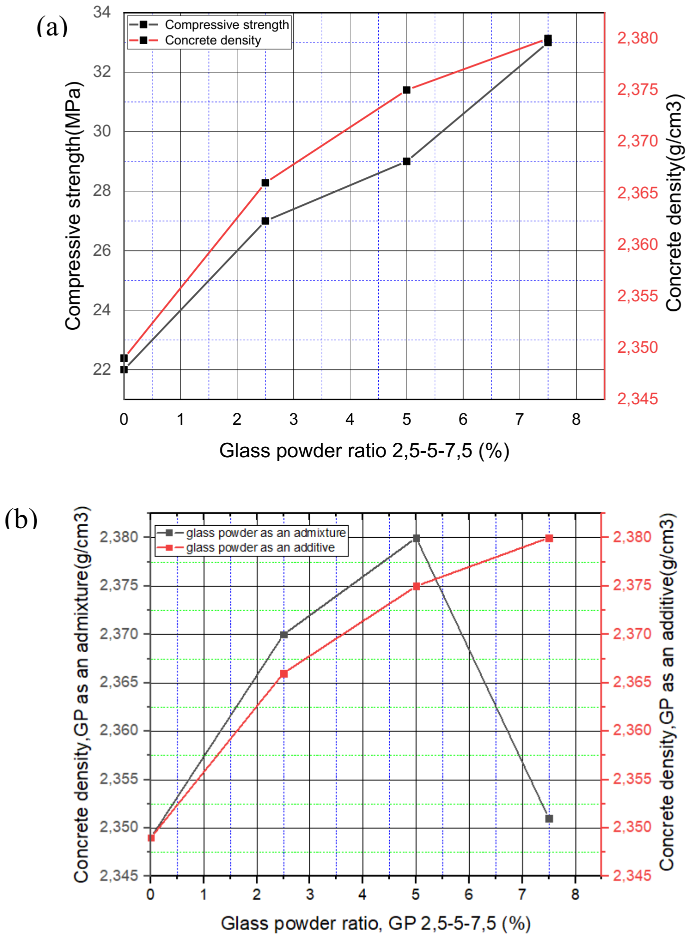

Figure 7. Graph, (a) correlation between the compressive strength, glass powder content used as a partial replacement of cement and the density of the hardened concrete, (b) correlation between the density of the two types of concrete using the glass Powder as an additive and admixture.

Conclusion

The man objective of this study were the assessing of the effect of used glass powder on the physical and mechanical properties of hydraulic concrete in the Congo environment. The partial obtained results shows that the concrete with the glass powder has a high compressive strength to compared the ordinary concrete without glass powder. The workability of set samples of concrete with glass powder is acceptable for a compaction improvement during the construction phase. For all samples, the concrete obtained with 5% glass powder content has good and stabilized compressive strength. 5% glass powder is the fixing point of the concrete composition. To compare the measured density, we can have noted that the studied concrete with glass powder as an added is a lightweight concrete according [32], which is suitable for minimizing construction costs in the local context of Congo due to the use of 100% cement. Furthermore, the sanitation (i.e., the environment) problem due to volume of solid waste can be minimized in Congo cities with the valorization of glass waste in construction industry. This research must be continued to complete the results on the effect of glass powder on the concrete microstructure, and the mechanical strengths of concrete at high temperatures.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards*:* This article does not contain any studies involving human or animal subjects.

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